[illegible]

Technical Paper 34

UNIVERSITY LIBRARY
SEP 11 1914
PRINCETON, N. J.

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

EXPERIMENTS WITH FURNACES FOR A HAND-FIRED RETURN TUBULAR BOILER

BY

SAMUEL B. FLAGG, GEORGE C. COOK
AND
FORREST E. WOODMAN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1914

The Bureau of Mines, in carrying out one of the provisions of its organic act—to disseminate information concerning investigations made—prints a limited free edition of each of its publications.

When this edition is exhausted copies may be obtained at cost price only through the Superintendent of Documents, Government Printing Office, Washington, D. C., who is the authorized agent of the Federal Government for the sale of all publications.

The Superintendent of Documents *is not an official of the Bureau of Mines.* His is an entirely separate office, and he should be addressed:

SUPERINTENDENT OF DOCUMENTS,
Government Printing Office,
Washington, D. C.

The general law under which publications are distributed prohibits the giving of more than one copy of a publication to one person. Additional copies must be purchased from the Superintendent of Documents. The price of this technical paper is 5 cents.

First edition. July, 1914.

CONTENTS.

Page.
Preface........ 4
Introduction........ 5
  General conditions of tests........ 6
  Deductions from tests........ 6
Acknowledgments........ 6
The fuel........ 7
Boiler and setting........ 7
  Air-admission devices........ 8
  Furnace arrangement........ 9
Testing equipment and apparatus........ 12
Method of conducting tests........ 12
  Starting and stopping the tests........ 12
  Methods of firing........ 13
    Coking method........ 13
    Alternate-spreading method........ 13
  Attention to fuel bed........ 14
  Use of supplementary air and steam jets........ 14
  Smoke observations........ 14
  Sampling and analysis of flue gases........ 14
  Size of fuel........ 15
  Use of steam and water in ash pit........ 15
Results of tests........ 15
Discussion of test results........ 24
  Effect of construction of furnace........ 24
  Effect of method of firing........ 26
  Effect of auxiliary devices........ 28
Summary and conclusions........ 28
Publications on fuel technology........ 30

TABLES.

Page.
TABLE 1. Principal dimensions of boiler and setting........ 7
2. Observed data and computed results of furnace tests........ 16
3. Principal results of furnace tests........ 24

ILLUSTRATIONS.

Page.
PLATE I. Sections of furnace showing arrangement during fourth series of tests. 12
FIGURE 1. Cross section of furnace, showing arrangement during first series of tests........ 9
2. Cross section of furnace, showing arrangement during second series of tests........ 10
3. Cross section of furnace, showing arrangement during third series of tests........ 11
4. Cross section of fuel bed in furnace fired by coking method........ 13

PREFACE.

In the course of its investigations looking to increased efficiency in the utilization of fuels belonging to or for the use of the Government, the Bureau of Mines has given especial attention to the methods of burning, without the production of objectionable smoke, coals containing much volatile matter, such as are the most readily available fuel in many cities. As a result of the growing opposition to the smoke nuisance, many of the large manufacturing plants at which high-volatile coal is burned are now supplied with mechanical stokers and furnaces of special design, by the use of which practically smokeless combustion is obtained. With the increasing use of mechanical stokers at large boiler plants, the problem of smoke abatement in many cities is becoming more and more that of assuring smokeless combustion at the small plants—those having hand-fired furnaces and return tubular boilers.

To increase the efficiency of furnaces at such plants and to lessen the annoyance from smoke, various modifications in the arrangement of brickwork, combustion spaces, and air inlets have been proposed. In an endeavor to aid better furnace design, the Bureau of Mines undertook a series of experiments to determine the relative efficiency of various methods of admitting air to a hand-fired furnace and of mixing the burning gases so as to insure complete combustion of the volatile matter in the coal before the gases reach the heating surface of the boiler. This paper records the results obtained by using certain arrangements of arches, deflecting walls, and air inlets, such as are typical of many proposed furnace designs. Some of the results are desirable, others are not.

As Mr. Flagg points out, the experiments indicate the possibility of designing hand-fired furnaces in which coals containing much volatile matter can be burned to generate steam without the production of objectionable smoke.

O. P. Hood,
Chief Mechanical Engineer.

EXPERIMENTS WITH FURNACES FOR A HAND-FIRED RETURN TUBULAR BOILER.

By **Samuel B. Flagg, George C. Cook, and Forrest E. Woodman.**

INTRODUCTION.

Although most of the large steam power plants to-day have mechanical stokers, yet the total number of hand-fired furnaces still exceeds by far those in which such stokers are used. This statement is true not only as regards commercial plants but as regards plants operated by the Federal Government.

For many years it was the practice in this country to set practically all hand-fired boilers, both water tube and fire tube, according to certain standard designs without regard to the character of the fuel to be used. Most of these standard settings were developed in the eastern States where the fuel used was, as a rule, either a small size of anthracite or a bituminous coal containing relatively little volatile matter. The adoption of such furnace designs for plants where the more gaseous coals were to be used resulted not only in large losses from incomplete combustion, but also in the production of much dense smoke.

With the increased opposition to smoke came a greater demand for its elimination. This demand was directed first at the larger plants, and because of the greater possibilities of reducing operating expenses and the greater assurance of smoke prevention by the use of mechanical stokers, these plants generally abandoned hand firing. Various devices were also developed and sold for hand-fired boilers, but most of them took little or no account of furnace design. Within the last few years, however, the demand for the reduction of smoke emission from hand-stoked furnaces has become more insistent and much more attention has been given to the design of hand-fired furnaces, including those for small plants.

The tests reported in this paper were undertaken for the purpose of determining the effect on furnace efficiency and on smoke emission of certain features of furnace design and of different methods of operation.

The results of the tests show that it is possible to develop furnaces that will, if properly handled, meet the requirements of city smoke

Original from PRINCETON UNIVERSITY

enactments. With the proof of this possibility will come further improvement in all hand-fired boiler furnaces.

GENERAL CONDITIONS OF TESTS.

The furnace used in the tests was connected with a small horizontal return tubular boiler having rather large fire tubes. Six series of tests were made. In the first series there was an arch over the grate and the bridge wall; in the second series a deflecting baffle was added back of this arch; in the third series there was no arch directly over the grate, but the part over the bridge wall and the deflecting baffle were retained; in the fourth and fifth series of tests there were mixing wing walls and heat-retaining masses in the combustion space back of the bridge wall; and in the sixth series a lengthened passage for the gases through the boiler tubes was provided.

DEDUCTIONS FROM TESTS.

Certain conclusions drawn from the results of the tests are believed to apply to the settings of practically all hand-fired boilers of the return-tubular type, when fired as described in this paper. These deductions are as follows:

1. The operation, at rating, of hand-fired boilers of this type in most American cities without violation of their smoke ordinances is physically possible, and with proper boiler-room supervision can be accomplished, although it requires an attention to firing methods not given by the average fireman.
2. The prevention of smoke may be more easily accomplished when the coking method of firing is employed than when the spreading method is used.
3. The use of supplementary air immediately after firing tends to increase the over-all efficiency and to abate smoke.
4. A brick arch directly over the fire and underneath the boiler shell results in lower over-all efficiency and in the production of more smoke. The screening of heating surface in the combustion chamber from direct radiation from the brickwork tends to lower the combined efficiency.

Further conclusions as regards the effects of certain types of arch are presented at the end of this paper.

ACKNOWLEDGMENTS.

The authors are indebted to R. H. Kuss and L. R. Stowe, formerly of the Chicago smoke-inspection department, for helpful criticism and suggestions at the time plans were being formulated for these experiments, and to E. W. Miller, L. L. Satler, jr., E. T. Gregg, Charles Schramm, Lauson Stone, and A. C. Fieldner, of the Bureau

of Mines, for cooperation in conducting the tests, computing results, and analyzing samples of coal and refuse.

THE FUEL.

The fuel used throughout the experiments was slack coal from two mines near Pittsburgh, Pa., that were working the Pittsburgh bed. The coal was selected as being representative of that used for steaming purposes throughout the Pittsburgh district, and, because of the proportion and character of its volatile matter, as being typical of coals difficult to burn without smoke in a hand-fired furnace.

The proportions of nut and fine coal varied considerably in the different shipments received, but the fuel for the tests was used just as it was taken from the cars, no selecting nor screening being done at any time. The proximate analyses of the test samples are presented in Table 2 (pp. 16–23), and an ultimate analysis (moisture free) of the coal from each mine is given below:

Ultimate analyses on moisture-free basis of coals used in tests.

	Per cent.	
Hydrogen	4.93	4.8
Carbon	74.33	72.4
Nitrogen	1.38	1.4
Oxygen	4.44	6.7
Sulphur	2.79	1.7
Ash	12.13	13.0

BOILER AND SETTING.

The principal data relative to the boiler and setting are given in Table 1. The figures in this table apply to all tests.

TABLE 1.—*Principal dimensions of boiler and setting.*

Boiler:		
Type		Horizontal return tubular.
Rated capacity, at 10 square feet per boiler-horsepower	horsepower	83
Length of shell	feet	16
Diameter of shell	inches	60
Number of tubes		44
External diameter of tubes	inches	4.00
Internal diameter of tubes	do	3.75
Water-heating surface of tubes	square feet	688
Water-heating surface of shell	do	126
Water-heating surface of tube sheets	do	19
Total water-heating surface	do	833
Furnace:		
Kind of grate		Plain.
Length of grate	feet	4.5
Width of grate	do	5.0
Area of grate	square feet	22.5
Width of air spaces	inches	½ to ⅝
Proportion of air spaces to grate surface	per cent	43

Furnace—Continued.		
Height of boiler shell above grate	inches	42
Least draft area (over bridgewall)	square feet	2.5
Depth of ash pit	inches	24
Stack:		
Construction		Steel, supported by guy wires.
Height of top above grate	feet	128
Diameter	inches	30
Area	square feet	4.9

In the first three series of tests the side walls of the setting were of brick. Each wall consisted of two 9-inch walls with an air space 1 inch wide between them. In the last three series the setting had a concrete outer wall 9 inches thick and a 9-inch fire-brick lining, separated by one thickness of tar paper.

AIR-ADMISSION DEVICES.

The admission of extra air after firings in series 1, 2, and 3 was accomplished by means of 14 rectangular openings equally spaced across the front wall of the furnace above the firing doors. These openings had a total area of 46 square inches, or about 2½ square inches per square foot of grate area, and were connected to a common duct or air passage in the wall that was approximately 8 by 10 inches and extended out through the side wall. A sliding door at the outer end of this duct enabled the fireman to cut off the air supply entirely or to regulate the volume of air admitted.

Eight rectangular openings having a total area of 115 square inches, or about 5 square inches per square foot of grate area, were used in the last three series. These openings were equally spaced across the front wall of the furnace and were divided into two separately controlled groups, one for each half, each group being equipped with a sliding damper in the boiler front for control of the air admission.

In each of two openings, one on each side of the furnace front and about over the centers of the firing doors, a high-pressure steam jet was placed. The jet pipe extended to within 1 inch of the inner face of the front wall and was pointed at the rear line of the grates. The direction of the jets was maintained the same throughout the tests. It was the intention also to keep the size of the opening in the jet pipe constant, and to this end the tips were removed as soon as they became burnt or badly corroded. The jets were made by plugging the one-fourth inch jet pipe with a pipe plug, in which was drilled a hole one-eighth inch in diameter.

In some of the tests the supplementary air was admitted through the rear face of the bridgewall, instead of at the front end of the furnace, 18 openings with a total area of 67 square inches, or about 3 square inches per square foot of grate area, being provided. The duct, approximately 8 by 10 inches, to which these openings were connected, is shown in figures 1, 2, and 3. The air admission was regulated by a sliding door similar to the one used for the duct at the front end.

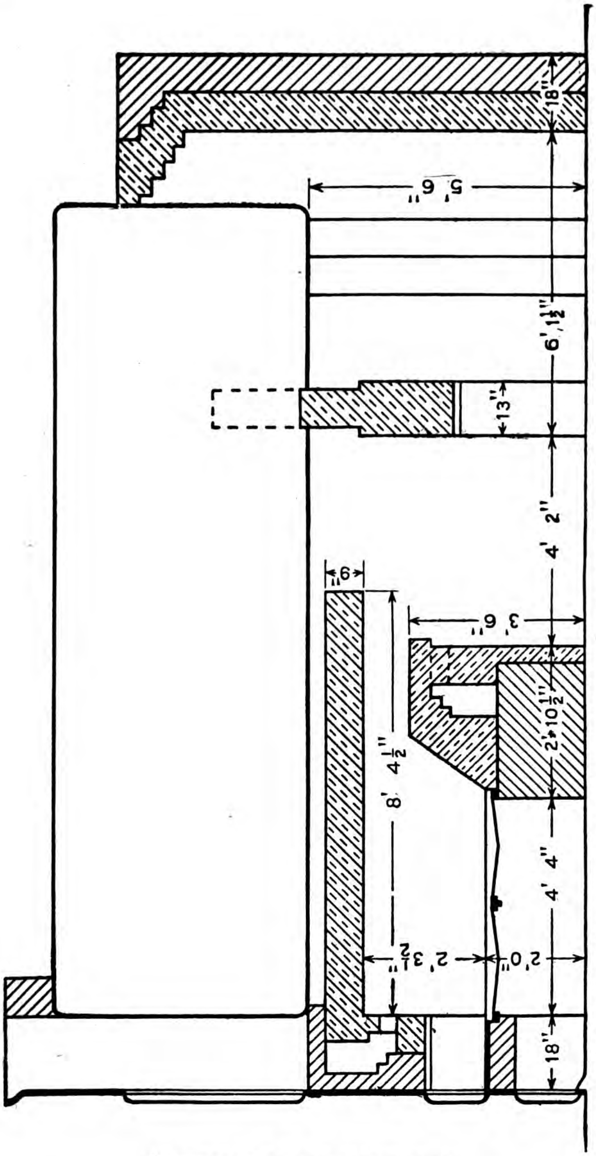

FIGURE 1.—Cross section of furnace, showing arrangement during first series of tests. Horizontal return tubular boiler, 60 inches by 16 feet, with forty-four 4-inch tubes.

FURNACE ARRANGEMENT.

Figure 1 shows the furnace arrangement throughout the first series of tests. It will be noted that the furnace arch extended from the front wall to about 1 foot back of the bridgewall. Before the second series of tests was started, the furnace arch was extended as indicated in figure 2 and a deflection arch was added back of the bridgewall for the purpose of deflecting the gases downward and causing them to mix better. For the third series the deflection arch and the rear part of the furnace arch were left unchanged, but the part of the furnace arch directly over the grates was removed, as shown in figure 3. After the removal of the front part of the furnace arch a

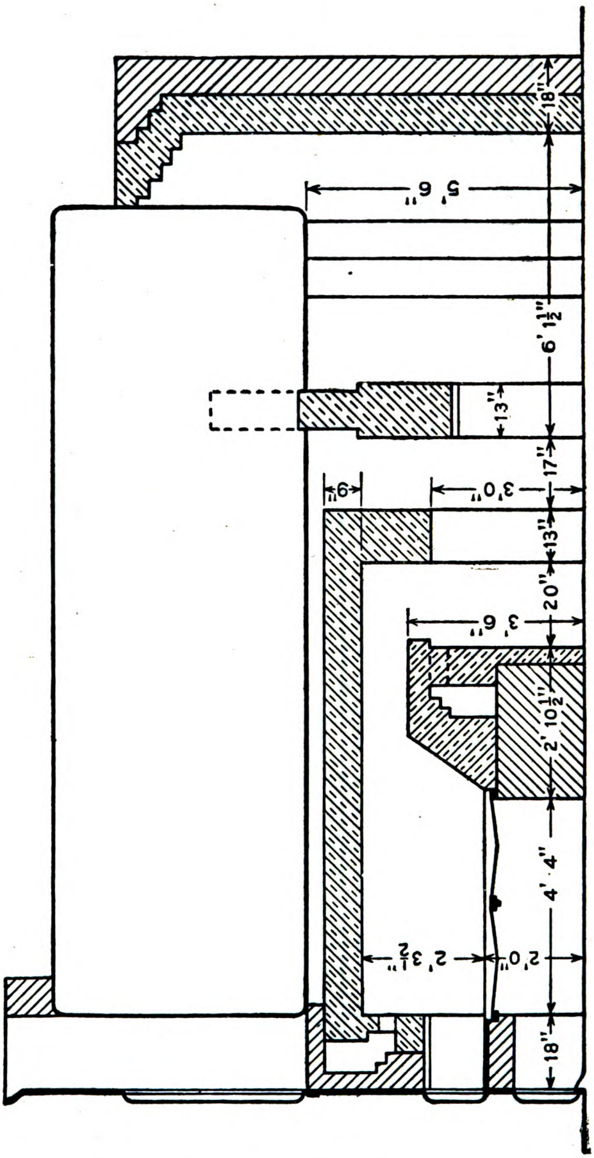

FIGURE 2.—Cross section of furnace, showing arrangement during second series of tests. Horizontal return tubular boiler, 60 inches by 16 feet, with forty-four 4-inch tubes.

4-inch curtain wall was built on top of the rear part so as to prevent the passage of gases between the arch and the boiler shell. In the setting for the fourth series, a brick pier dividing the combustion chamber into two parallel gas passages was substituted for the deflection arch and baffle wall. For the better mixing of the gases, wings were added to the side walls and to the front end of the brick pier, as shown in Plate I. A curtain wall, extending from the top to the shell, was erected at the front end of the pier, and tile were laid horizontally

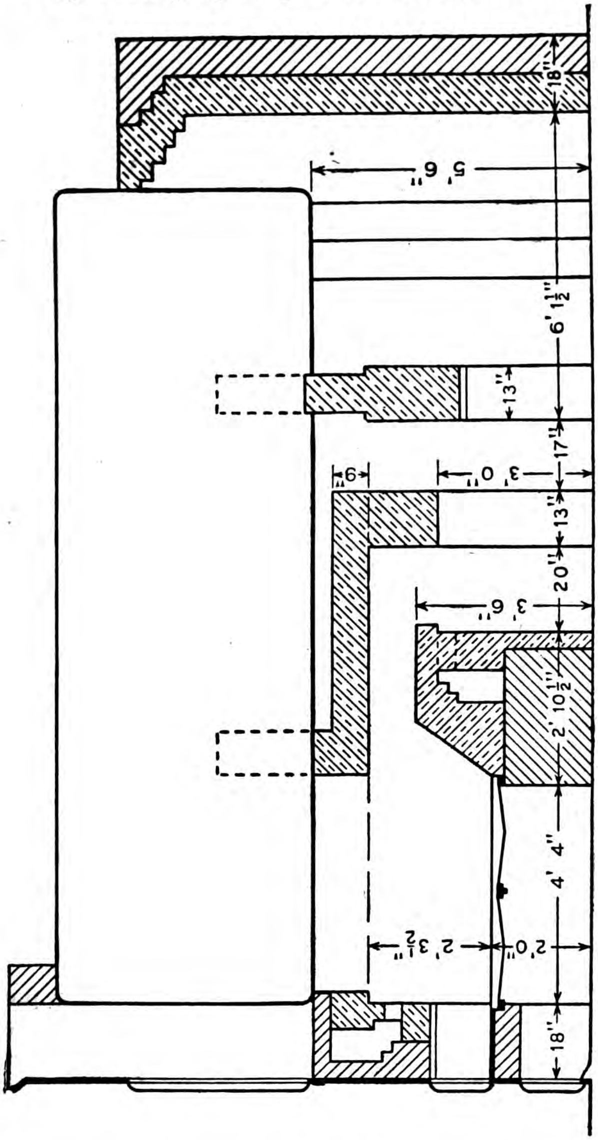

FIGURE 3.—Cross section of furnace, showing arrangement during third series of tests. Horizontal return tubular boiler, 60 inches by 16 feet, with forty-four 4-inch tubes.

from the top of the pier to the side walls. The setting for the fifth series was identical with that of the fourth, except that in the fifth series the horizontal tile in the combustion chamber were removed. The setting in the sixth series was the same as in the fourth, except that a baffle was erected across the back of the shell to cause the gases to pass through the lower 24 tubes to the front, return through the upper 20, and leave the boiler through a breeching at the rear. This setting gave the gases a double instead of a single pass through the tubes.

TESTING EQUIPMENT AND APPARATUS.

The water fed to the boiler during all tests was of the temperature it had as it came from the city mains. The quantity used was determined by means of a No. 22 Kennicott water weigher discharging into a feed tank. A duplex pump took the water from this tank and forced it into the boiler through a feed line connected to the blow-off pipe directly under the boiler.

In some tests the flue-gas temperatures were determined by means of a mercurial pyrometer; in others by means of an electric thermocouple. The hot end of the thermometer or of the thermocouple, as might be, was kept inside of a sheet-iron sampler or collector placed in the smoke box just under the damper, thus protecting the thermometer bulb from losing heat to the cooler boiler surfaces and walls. Other temperatures were read by means of the usual mercurial thermometers.

In all but six tests a modified Orsat apparatus was used for analyzing the flue gases, and in these tests a Precision CO_2 recorder was employed, check analyses being made with the Orsat apparatus at frequent intervals.

For "draft" measurements pressure gages of the differential type, as manufactured by several makers, were used. All smoke observations were made by comparison with the Ringlemann chart.[a]

The moisture in the steam was determined with a throttling calorimeter.

METHOD OF CONDUCTING TESTS.

The unit used in these tests was operated for the sole purpose of the investigations and the load was therefore practically constant throughout any one test, control being obtained by throttling an outlet delivering to the atmosphere.

STARTING AND STOPPING THE TESTS.

In starting and stopping the tests a modification of the "alternate method," as described in the American Society of Mechanical Engineers' code of 1899 for boiler trials, was used.

---

[a] Flagg, S. B., City smoke ordinances and smoke abatement: Bull. 49, Bureau of Mines, 1912, p. 27.

The fire was built up from a banked condition and the setting was heated to a temperature corresponding to normal running conditions. Soon after this condition had been reached the fire was cleaned. For the next 45 minutes or so the furnace was operated in the same manner as it was to be operated during the test, then starting readings were taken and the test was begun. At the close of the test the same method of procedure was followed, especial care being taken to have the fuel-bed conditions as they were when the test began.

METHODS OF FIRING.

Each series of tests was divided into two groups. The coking method of firing was followed throughout the tests of one group and the alternate-spreading method throughout the other.

COKING METHOD.

In firing by the coking method comparatively large charges of coal are fired at intervals of 15 minutes. The coal is heaped in a pile extending across the furnace and just inside the dead plate, where it is allowed to remain until the next firing (fig. 4). The volatile matter is slowly driven off by the heat of the furnace and at the end of 15 minutes the coal at the front should be coked. At the next firing the coke at the front is broken up and pushed to the rear by means of a hoe, care being taken to cover up any holes or thin spots in the fuel bed at the rear; then more green coal is fired, as previously described. The volatile matter distilled from the green coal passes over the incandescent coke at the rear and is consumed without smoke provided it is intimately mixed with the necessary air.

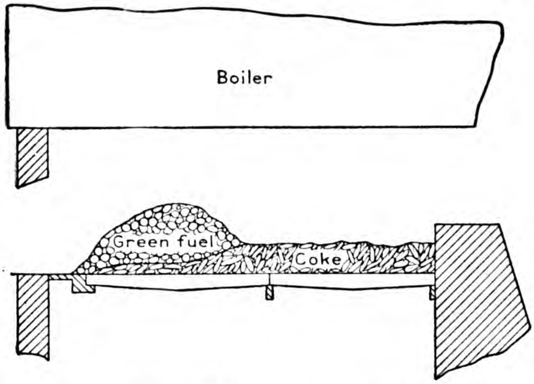

FIGURE 4.—Cross section of fuel bed in furnace fired by coking method.

In the tests recorded in this paper the time required to push back the partly coked charge and fire the fresh coal through the two firing doors was about 1½ minutes, except when conditions made slicing or other special attention necessary.

ALTERNATE-SPREADING METHOD.

In firing by the alternate-spreading method, small charges of coal are fired at intervals of 5 minutes on either side, thus making the interval between the consecutive firings of any one door 10 minutes.

Original from PRINCETON UNIVERSITY

The purpose in firing one side at a time is to allow the temperature of the furnace to be sustained by the incandescent fuel bed on the other side at such a point that the volatile matter driven off from the freshly charged fuel will be consumed.

In the tests recorded in this paper the time taken to make each firing was ordinarily between 15 and 30 seconds. In firing an effort was made to place the coal so as to maintain a uniformly level fuel bed and to prevent thin spots developing.

ATTENTION TO FUEL BED.

The quantity of coal charged at any one time varied according to the method of firing and also with the rate of combustion, but was kept as nearly uniform as possible throughout any one test. The fuel bed was sliced or raked only when necessary, and the records show that the frequency of slicing was about the same for both methods of firing. When the coking method was employed the fuel bed was necessarily leveled each time fuel was charged, but this was considered part of the regular firing routine, and, as no other raking was necessary, none was recorded.

USE OF SUPPLEMENTARY AIR AND STEAM JETS.

As has already been pointed out, each series of tests was composed of two groups. It will be noted in the tables of results that the tests of each group were made in the same order as regards the use of steam jets or air-admission openings. These auxiliary devices were in use 2 to 4 minutes after each firing, the time necessary depending on the device used and on the method of firing employed. In no instance was any device used continuously throughout the test.

SMOKE OBSERVATIONS.

Smoke observations were taken every 15 seconds during alternate periods of 15 minutes throughout the first 7 hours of the test and at intervals of 15 seconds throughout the last hour during which the cleaning period occurred. The effort was made to control conditions so as to develop about 100 per cent of the boiler's rated capacity each day and to keep the load fairly constant.

SAMPLING AND ANALYSIS OF FLUE GASES.

During most of the tests gas samples were collected continuously over half-hour periods and analyzed with the Orsat apparatus. In a few of the tests the gases were analyzed by a CO_2 recorder and a number of check samples analyzed with the Orsat apparatus to establish the correctness of the recorder readings.

SIZE OF FUEL.

The percentages of nut and fine coal given in the tables of results are the averages of estimated percentages noted during the tests. No sizing tests were made, but the percentages were estimated each time a load of coal was weighed for the test.

USE OF STEAM AND WATER IN ASH PIT.

On account of trouble experienced during some of the preliminary tests from clinker sticking to the grates and walls, it was decided to introduce steam into the ash pit, and because of the lack of available exhaust steam, live steam had to be used. All tests of the first three series were conducted in this manner, but no measurements of the quantity of steam used nor any corrections for such use were made. In the last three series of tests water was used in the ash pit in place of steam.

RESULTS OF TESTS.

The principal data in regard to the details of each test and the results obtained are given in Table 2 following.

TABLE 2.—*Observed data and computed results of furnace tests.*

SERIES 1.

[Figures in parenthesis are A. S. M. E. code number.]

Number of test.	Construction of furnace.	Method of firing.	Auxiliary devices used.	Size of fuel.		Date of trial.	Duration of trial.
				Nut.	Slack.		
1	2	3 (80)	4	5 (23)		6 (1)	7 (2)
				P. ct.	*P. ct.*	1912.	*Hours.*
S-501	As shown in fig. 1	Coking	None	10	90	June 17	8.08
S-502	do	do	Air over fire	10	90	June 18	8.00
S-503	do	do	Air through bridgewall	10	90	June 19	8.00
S-504	do	do	Steam jets over fire	10	90	June 20	8.00
S-505	do	do	Steam jets over fire, air over fire	10	90	June 21	8.08
S-506	do	Alternate spreading.	None	10	90	June 24	8.00
S-507	do	do	Air over fire	5	95	June 25	8.03
S-508	do	do	Air through bridgewall	10	90	June 26	8.03
S-509	do	do	Steam jets over fire	10	90	June 28	8.00
S-510	do	do	Steam jets over fire, air over fire	15	85	July 1	8.00

SERIES 2.

S-511	As shown in fig. 2	Coking	None	10	90	July 16	8.00
S-512	do	do	Air over fire	15	85	July 17	8.00
S-513	do	do	Air through bridgewall	12	88	July 18	8.00
S-514	do	do	Steam jets over fire	20	80	July 23	8.00
S-515	do	do	Steam jets over fire, air over fires	10	90	July 24	8.00
S-516	do	Alternate spreading.	None	10	90	July 25	8.00
S-517	do	do	Air over fire	10	90	July 26	8.00
S-520	do	do	Air through bridgewall	15	85	Aug. 5	8.00
S-521	do	do	Steam jets over fire	10	90	Aug. 6	8.00
S-522	do	do	Steam jets over fire, air over fire	15	85	Aug. 7	8.05

SERIES 3.

S-523	As shown in fig. 3	Coking	None	25	75	Aug. 12	8.00
S-545	do	do	Air over fire	15	85	Sept. 13	8.00
S-525	do	do	Air through bridgewall	15	85	Aug. 14	8.00
S-526	do	do	Steam jets over fire	25	75	Aug. 15	8.00
S-527	do	do	Steam jets over fire, air over fire	15	85	Aug. 16	8.00
S-530	do	Alternate spreading.	None	20	80	Aug. 19	8.00
S-531	do	do	Air over fire	15	85	Aug. 20	8.00
S-532	do	do	Air through bridgewall	25	75	Aug. 21	8.00
S-533	do	do	Steam jets over fire	25	75	Aug. 22	8.00
S-534	do	do	Steam jets over fire, air over fire	25	75	Aug. 23	8.00

SERIES 4.

						1913.	
S-585	As shown in Plate I	Coking	Air over fire	25	75	May 12	9.08
S-586	do	do	Steam jets over fire and air over fire	15	85	May 13	8.00
S-587	do	Alternate spreading.	Air over fire	20	80	May 15	8.93
S-588	do	do	Steam jets over fire and air over fire	25	75	May 16	9.02

SERIES 5.

S-603	As shown in Plate I	Coking	Air over fire	30	70	Aug. 19	8.50
S-604	do	do	Steam jets over fire and air over fire	25	75	Aug. 20	8.90
S-605	do	Alternate spreading.	Air over fire	20	80	Aug. 21	8.72
S-606	do	do	Steam jets over fire and air over fire	25	75	Aug. 22	8.60

SERIES 6.

S-576	As shown in Plate I	Coking	Air over fire	30	70	Apr. 23	8.68
S-577	do	do	Steam jets over fire and air over fire	35	65	Apr. 28	9.00
S-598	do	Alternate spreading.	Air over fire	30	70	July 31	8.82
S-600	do	do	Steam jets over fire and air over fire	30	70	Aug. 14	8.90

TABLE 2.—*Observed data and computed results of furnace tests*—Continued.

SERIES 1.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Average pressures.			Average temperatures.				Fuel.								Proximate analysis of fuel as fired.					Analyses of ash and refuse.					
		Force of draft (inches of water).						Total weight of fuel consumed.		Ash and refuse.		Total weight of combustible determined from—									Ash.			Clinker.		
	Steam gage.	Hood.	Furnace.	External air.	Fire room.	Feed water entering boiler.	Escaping gases.	As fired.	Dry.	Total.	Clinker.	Actual weight of ash.	Analyses of ash and coal.	Ash and refuse as a percentage of dry coal.	Combustible matter in refuse.	Moisture.	Volatile combustible.	Fixed carbon.	Ash.	Sulphur (separately determined).	Combustible (dry sample).	Earthy matter (dry sample).	Moisture (as received).	Combustible (dry sample).	Earthy matter (dry sample).	Moisture (as received).
1	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
	(11.1)	(12)	(13)	(15)	(16)	(20)	(21)	(25)	(27)	(28)	(29)	(30)	(30)	(31)		(34)	(33)	(32)	(35)	(36)	(44)	(45)		(44)	(45)	
	Lbs. per sq. in.			*° F.*	*° F.*	*° F.*	*° F.*	*Lbs.*	*Lbs.*	*Lbs.*	*P. ct.*	*Lbs.*	*Lbs.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P.*
S-501	82.5	0.33	0.20	78	88	71.2	601	2,894	2,829	300	49	2,529	2,446	10.6	16.9	2.24	34.07	52.21	11.48	2.62	24.75	75.25	0.17	8.73	91.27	9.54
S-502	83.5	.33	.19	71	82	71.2	575	2,751	2,688	311	52	2,377	2,314	11.6	21.0	2.29	33.95	52.54	11.22	2.89	36.64	63.36	.31	6.60	93.40	6.67
S-503	82.9	.30	.21	68	81	70.9	576	2,917	2,838	290	49	2,548	2,479	10.2	22.4	2.71	34.71	52.50	10.08	2.56	30.18	69.82	.31	14.24	85.76	11.47
S-504	83.8	.27	.17	70	82	70.5	581	3,003	2,944	340	58	2,604	2,539	11.5	16.9	1.96	34.11	52.36	11.57	2.52	26.81	73.19	.27	9.75	90.25	7.94
S-505	84.6	.20	.14	70	86	70.5	549	2,830	2,773	310	59	2,463	2,398	11.2	15.6	2.01	34.74	51.69	11.56	2.53	26.56	73.44	.26	7.97	92.03	11.81
S-506	84.0	.20	.14	73	88	71.0	554	3,035	2.938	328	70	2,610	2,514	11.2	17.8	3.19	33.50	51.26	12.05	2.70	21.80	78.20	.11	16.06	83.94	15.11
S-507	83.8	.18	.14	79	94	71.9	536	2,739	2,660	307	67	2,353	2,305	11.5	16.9	2.89	34.28	51.75	11.08	2.60	23.49	76.51	.17	13.60	86.40	14.22
S-508	84.8	.15	.12	80	91	72.4	541	2,898	2,828	345	72	2,483	2,439	12.2	20.7	2.41	34.49	52.16	10.94	2.55	32.20	67.80	.14	16.29	83.71	13.44
S-509	83.0	.17	.14	75	93	73.9	545	3,044	2,966	382	64	2,584	2,580	12.9	19.2	2.57	35.42	51.75	10.26	2.40	21.15	78.85	.07	18.09	81.91	11.28
S-510	83.8	.14	.11	76	89	74.9	556	2,927	2,868	325	66	2,543	2,499	11.3	16.9	2.03	35.45	51.80	10.72	2.36	23.96	76.04	.08	13.33	86.67	10.17

SERIES 2.

S-511	83.3	0.30	0.15	81	89	79.7	630	2,954	2,859	297	52	2,562	2,484	10.4	18.9	3.23	34.06	51.92	10.79	2.61	24.13	75.87	0.18	14.11	85.89	15.82
S-512	85.0	.23	.12	80	92	79.8	581	2,798	2,731	274	53	2,457	2,413	10.0	17.4	2.39	34.76	53.21	9.64	2.33	22.41	77.59	.16	13.10	86.90	11.68
S-513	84.2	.22	.12	78	91	79.8	576	2,808	2,750	344	55	2,406	2,385	12.5	15.5	2.08	35.10	51.73	11.09	2.48	18.51	81.49	.09	12.95	87.05	15.67
S-514	85.2	.24	.15	74	89	76.1	577	3,047	2,968	320	62	2,648	2,589	10.8	18.2	2.59	36.03	50.84	10.54	2.87	24.36	75.64	.22	14.38	85.62	8.94
S-515	83.8	.23	.15	71	89	75.3	587	2,796	2,714	293	63	2,421	2,366	10.8	14.0	2.93	35.24	50.84	10.99	2.70	25.06	74.94	.23	7.52	92.48	8.36
S-516	83.8	.17	.11	76	87	74.8	550	2,861	2,781	293	58	2,488	2,400	10.5	17.1	2.79	35.00	50.64	11.57	2.87	21.91	78.09	.11	13.67	86.33	14.24
S-517	84.5	.18	.12	73	81	74.1	559	2,838	2,773	315	66	2,458	2,401	11.4	20.8	2.28	36.39	50.53	10.80	2.69	29.24	70.76	.13	16.60	83.40	11.35
S-520	83.6	.15	.10	68	79	72.2	565	2,742	2,668	299	62	2,369	2,328	11.2	20.2	2.69	35.96	51.14	10.21	2.62	28.00	72.00	.13	15.46	84.54	10.98
S-521	84.0	.12	.12	71	88	72.2	542	2,953	2,872	355	70	2,517	2,471	12.4	22.4	2.75	35.31	51.08	10.86	2.65	38.48	61.52	.18	15.55	84.45	4.81
S-522	84.2	.13	.10	75	91	72.3	534	2,853	2,768	298	69	2,470	2,373	10.8	24.0	2.99	34.84	50.84	11.33	2.65	29.50	70.50	.11	21.65	78.35	10.98

SERIES 3.

S-523	82.8	0.19	0.15	78	85	73.0	568	2,628	2,570	309	65	2,261	2,224	12.0	23.3	2.20	35.39	51.96	10.45	2.71	28.03	71.97	0.20	20.69	79.31	7.39
S-545	83.7	.18	.13	72	86	75.2	526	2,664	2,560	325	46	2,235	2,220	12.7	17.8	3.92	34.65	50.86	10.57	2.42	19.80	80.20	.00	15.47	84.53	5.56
S-525	84.2	.25	.18	78	86	73.9	549	2,606	2,546	240	58	2,306	2,239	9.4	20.2	2.31	35.76	51.99	9.94	2.67	20.53	79.47	.32	19.80	80.20	13.58
S-526	84.8	.21	.17	74	84	74.3	542	2,649	2,591	295	56	2,296	2,265	11.4	19.2	2.20	34.89	52.74	10.17	2.61	24.23	75.77	.28	15.11	84.89	12.50
S-527	84.2	.17	.14	72	81	74.2	534	2,490	2,427	267	54	2,160	2,118	11.0	17.7	2.55	35.31	51.65	10.49	2.65	20.98	79.02	.05	14.89	85.11	10.58
S-530	84.6	.19	.15	77	89	75.6	561	2,741	2,675	286	63	2,389	2,317	10.7	18.9	2.42	34.88	51.63	11.07	2.48	21.58	78.42	.11	17.32	82.68	15.29
S-531	85.0	.18	.13	77	86	75.8	537	2,619	2,551	295	58	2,256	2,220	11.6	17.1	2.59	34.69	51.99	10.73	2.92	23.01	76.99	.00	12.75	87.25	3.76
S-532	84.0	.17	.14	77	85	75.9	529	2,592	2,520	279	61	2,241	2,203	11.1	19.5	2.76	34.54	52.55	10.15	2.36	25.47	74.53	1.24	15.77	84.23	8.37
S-533	85.0	.12	.12	79	89	76.0	526	2,707	2,621	302	59	2,319	2,296	11.5	14.4	3.16	34.64	51.78	10.42	2.51	21.16	78.84	.10	9.68	90.32	11.91
S-534	85.2	.12	.10	70	81	75.7	500	2,607	2,556	321	64	2,235	2,229	12.6	18.2	1.95	35.98	51.78	10.29	2.60	26.87	73.13	.95	13.36	86.64	9.42

SERIES 4.

S-585	84.4	0.23	0.16	53	78	65.7	588	3,207	3,125	509	41	2,616	2,606	16.3	33.0	2.55	34.13	52.37	10.95	1.90	52.14	47.86	16.00	5.20	94.80	2.19
S-586	82.9	.24	.17	69	86	65.9	587	2,685	2,618	444	32	2,174	2,093	17.0	42.3	2.48	33.73	51.22	12.57	1.81	56.43	43.57	11.57	11.91	88.09	1.97
S-587	85.5	.18	.13	66	86	64.2	583	3,232	3,145	442	43	2,703	2,697	14.1	20.0	2.69	34.22	51.96	11.13	1.68	30.26	69.74	31.70	6.17	93.83	.12
S-588	85.6	.18	.12	71	88	64.7	563	3,259	3,140	389	39	2,751	2,690	12.4	20.1	3.65	33.48	51.45	11.42	1.72	28.30	71.70	13.97	7.35	92.65	4.50

SERIES 5.

S-603	82.5	0.15	0.11	83	97	80.0	574	2,753	2,674	425	38	2,249	2,243	15.9	24.5	2.86	34.30	50.94	11.90	2.13	35.27	64.73	11.99	7.14	92.86	5.54
S-604	82.1	.13	.11	77	96	80.0	526	2,853	2,772	462	45	2,310	2,290	16.7	29.0	2.83	33.54	51.41	12.22	1.78	49.60	50.40	10.11	4.07	95.93	.22
S-605	81.0	.13	.09	76	91	80.0	559	2,864	2,778	432	50	2,346	2,299	15.6	25.4	3.02	33.83	50.29	12.86	1.82	38.87	61.13	18.54	11.87	88.13	7.41
S-606	81.2	.12	.10	76	91	79.3	547	2,811	2,728	414	49	2,314	2,313	15.2	24.0	2.96	34.46	51.38	11.20	1.91	37.00	63.00	16.81	10.59	89.41	......

SERIES 6.

S-576	84.4	0.34	0.10	76	93	58.0	537	2,714	2,645	419	35	2,226	2,203	15.8	37.4	2.56	34.16	52.78	10.50	1.67	52.99	47.01	8.91	8.48	91.52	7.49
S-577	83.8	.41	.09	46	76	59.0	560	2,739	2,610	454	27	2,156	2,088	17.4	37.7	4.71	32.66	49.81	12.82	1.74	47.57	52.43	14.22	10.99	89.01	4.94
S-598	79.5	.30	.08	85	100	78.3	563	2,593	2,535	387	52	2,148	2,183	15.3	21.2	2.24	35.39	51.98	10.39	1.80	35.95	64.05	16.05	7.77	92.23	4.75
S-600	79.4	.34	.07	....	....	78.5	559	2,846	2,769	363	55	2,406	2,407	13.1	19.3	2.71	35.07	51.96	10.26	2.03	37.34	62.66	17.35	4.57	95.43	7.25

TABLE 2.—*Observed data and computed results of furnace tests*—Continued.

SERIES 1.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Fuel consumed per hour.						Calorific value of fuel per pound by oxygen calorimeter.			Quality of steam.		Water evaporation.							
	Dry coal.	Combustible, determined from—		Dry coal per square foot of grate area.	Combustible per square foot water-heating surface, determined from—							Water fed to boiler.		Actual corrected for quality of steam.	Factor of evaporation.	Equivalent converted into dry steam from and at 212° F.	Per hour.		
																	Corrected for quality of steam.	Equivalent from and at 212° F.	
		Actual weight of ash.	Analysis of ash and coal.		Actual weigh of ash	Analysis of ash and coal.	As received.	Dry fuel.	Combustible.	Moisture.	Factor of correction (dry steam unity).	Total weight.	Equivalent from and at 212° F.					Total.	Per square foot of water-heating surface.
1	**34** (46)	**35** (47)	**36** 47.1	**37** (48)	**38** (49)	**39** (49.1)	**40**	**41** (50)	**42** (51)	**43** (54)	**44** (56)	**45** (57)	**46** (58)	**47** (59)	**48** (60)	**49** (61)	**50** (62)	**51** (63)	**52** (64)
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*B. t. u.*	*B. t. u.*	*B. t. u.*	*Per cent.*	*Per cent.*	*Lbs.*	*Lbs.*	*Lbs.*		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
S-501.....	350	313	303	15.56	0.376	0.364	13,097	13,397	15,179	1.2	0.991	18,731	22,159	18,652	1.183	21,959	2,297	2,718	3.26
S-502.....	336	297	289	14.93	.357	.347	13,126	13,433	15,176	1.1	.991	19,026	22,508	18,855	1.183	22,305	2,357	2,788	3.35
S-503.....	355	318	310	15.78	.382	.372	13,244	13,613	15,187	1.4	.989	19,165	22,672	18,954	1.183	22,423	2,369	2,803	3.36
S-504.....	368	326	317	16.36	.391	.381	13,138	13,401	15,194	1.1	.991	20,094	23,791	19,913	1,184	23,577	2,489	2,947	3.54
S-505.....	343	305	297	15.24	.366	.357	13,109	13,378	15,167	1.2	.991	19,777	23,416	19,599	1.184	23,205	2,426	2,872	3.45
S-506.....	367	326	314	16.31	.391	.377	12,863	13,288	15,178	1.1	.991	20,709	24,499	20,523	1.183	24,279	2,565	3,035	3.64
S-507.....	331	293	287	14.71	.352	.345	13,055	13,444	15,176	1.3	.990	19,828	23,437	19,630	1.182	23,203	2,445	2,890	3.47
S-508.....	352	309	304	15.64	.371	.365	13,163	13,489	15,192	1.2	.991	20,685	24,450	20,499	1.182	24,230	2,553	3,017	3.62
S-509.....	371	323	322	16.49	.388	.387	13,183	13,531	15,124	1.0	.992	20,716	24,445	20,550	1.180	24,249	2,569	3,031	3.64
S-510.....	358	318	312	15.91	.382	.375	13,194	13,468	15,122	1.1	.991	20,171	23,782	19,989	1.179	23,567	2,499	2,946	3.54

SERIES 2.

S-511.....	357	320	310	15.87	0.384	0.372	13,052	13,487	15,179	1.1	0.991	19,594	23,003	19,418	1.174	22,797	2,427	2,850	3.42
S-512.....	341	307	302	15.15	.369	.363	13,365	13,693	15,194	.8	.994	19,782	23,224	19,663	1.174	23,084	2,458	2,886	3.46
S-513.....	344	301	298	15.29	.361	.358	13,208	13,489	15,214	1.1	.991	20,151	23,657	19,970	1.174	23,445	2,496	2,931	3.52
S-514.....	371	331	324	16.49	.397	.389	13,198	13,549	15,192	1.1	.991	20,342	23,963	20,159	1.178	23,747	2,520	2,968	3.56
S-515.....	339	303	296	15.07	.364	.355	13,154	13,552	15,282	1.0	.992	19,601	23,110	19,444	1.179	22,924	2,430	2,866	3.44
S-516.....	348	311	300	15.47	.373	.360	13,027	13,401	15,212	1.2	.991	19,727	23,258	19,549	1.179	23,048	2,444	2,881	3.46
S-517.....	347	307	300	15.42	369	360	13,151	13,457	15,129	1.2	.991	19,968	23,562	19,788	1.180	23,350	2,474	2,919	3.50
S-520.....	334	296	291	14.84	.355	.349	13,178	13,541	15,129	1.2	.991	19,734	23,326	19,556	1.182	23,115	2,444	2,889	3.47
S-521.....	359	315	309	15.96	.378	.371	13,073	13,444	15,134	.9	.993	20,008	23,649	19,868	1.182	23,484	2,484	2,936	3.52
S-522.....	344	307	295	15.29	.369	.354	12,971	13,370	15,138	1.0	.992	19,868	23,484	19,709	1.182	23,296	2,448	2,894	3.47

SERIES 3.

S-523.....	321	283	278	14.27	0.340	0.334	13,180	13,477	15,089	1.3	0.990	19,065	22,516	18,874	1.181	22,290	2,359	2,786	3.34
S-545.....	320	279	278	14.22	.335	.334	12,985	13,514	15,185	1.1	.991	19,198	22,634	19,025	1.179	22,430	2,378	2,804	3.37
S-525.....	318	288	280	14.13	.346	.336	13,257	13,570	15,106	1.8	.986	19,155	22,603	18,887	1.180	22,287	2,361	2,786	3.34
S-526.....	324	287	283	14.40	.345	.340	13,306	13,604	15,183	1.2	.991	19,346	22,828	19,172	1.180	22,623	2,396	2,828	3.39
S-527.....	303	270	265	13.47	.324	.318	13,158	13,504	15,133	1.9	.985	19,323	22,801	19,033	1.180	22,459	2,379	2,807	3.37
S-530.....	334	299	290	14.84	.359	.348	13,120	13,446	15,165	1.5	.988	19,484	22,972	19,250	1.179	22,696	2,406	2,837	3.41
S-531.....	319	282	278	14.18	.339	.334	13,131	13,480	15,149	1.5	.988	19,391	22,843	19,158	1.178	22,568	2,395	2,821	3.39
S-532.....	315	280	275	14.00	.336	.330	13,228	13,604	15,190	1.3	.990	19,650	23,148	19,454	1.178	22,917	2,432	2,865	3.44
S-533.....	328	290	287	14.58	.348	.345	13,138	13,567	15,203	1.3	.990	19,481	22,949	19,286	1.178	22,719	2,411	2,840	3.41
S-534.....	320	279	279	14.22	.335	.335	13,313	13,577	15,169	1.2	.991	19,862	23,417	19,683	1.179	23,206	2,460	2,901	3.48

SERIES 4.

S-585	344	288	287	15.29	0.346	0.345	12,829	13,165	14,832	1.7	0.987	20,936	24,872	20,664	1.188	24,549	2,276	2,704	3.246
S-586	327	272	262	14.53	.327	.314	12,591	12,911	14,823	2.1	.984	17,458	20,723	17,179	1.187	20,391	2,147	2,549	3.060
S-587	352	303	302	15.64	.364	.363	12,829	13,183	14,886	1.6	.988	22,396	26,629	22,127	1.189	26,309	2,478	2,946	3.537
S-588	348	305	298	15.47	.366	.358	12,602	13,079	14,837	1.5	.988	22,515	26,770	22,245	1.189	26,449	2,466	2,932	3.520

SERIES 5.

S-603	315	265	264	14.00	0.318	0.317	12,632	13,003	14,818	1.5	0.988	20,332	23,849	20,088	1.173	23,563	2,363	2,772	3.328
S-604	311	260	257	13.82	.312	.308	12,580	12,946	14,809	1.5	.988	21,697	25,451	21,437	1.173	25,146	2,409	2,825	3.391
S-605	319	269	264	14.18	.323	.317	12,449	12,836	14,798	1.7	.987	21,278	24,938	21,001	1.172	24,613	2,408	2,823	3.389
S-606	317	269	269	14.09	.323	.323	12,694	13,081	14,787	1.4	.989	20,760	24,351	20,532	1.173	24,084	2,387	2,800	3.361

SERIES 6.

S-576	305	256	254	13.56	0.307	0.305	12,920	13,261	14,863	....	0.985	19,853	23,744	19,555	1.196	23,388	2,253	2,694	3.234
S-577	290	240	232	12.89	.288	.278	12,247	12,852	14,850	....	.985	18,508	22,099	18,230	1.194	21,767	2,026	2,419	2.904
S-598	287	244	248	12.76	.293	.298	12,983	13,280	14,859	2.3	.982	19,346	22,712	18,998	1.174	22,304	2,154	2,529	3.036
S-600	311	270	270	13.82	.324	.324	12,964	13,325	14,897	1.7	.987	20,797	24,395	20,527	1.173	24,078	2,306	2,705	3.247

Original from PRINCETON UNIVERSITY

TABLE 2.—*Observed data and computed results of furnace* **tests**—Continued.

SERIES 1.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Horsepower.			Economic results (pounds of water evaporated per pound of fuel).					Efficiency of—			Smoke.			Firing.		Analysis of the dry gases.			
					Equivalent from and at 212° F.															
							Combustible determined from—													
	Developed on test.	Rated capacity at 10 square feet per boiler horsepower.	Per cent of rated horsepower developed.	Apparent under actual conditions as fired.	As fired.	Dry.	Actual weight of ash.	Analyses of ash and coal.	Boiler from actual weight of ash.	Boiler from analyses of ash and coal.	Boiler and grates.	Average density of smoke.	Average minutes of dense smoke per hour.	Maximum minutes of dense smoke per hour.	Thickness of fire.	Interval between normal firing.	Carbon dioxide (CO_2).	Oxygen (O_2).	Carbon monoxide (CO).	Nitrogen (N_2).
1	53 (65)	54 (66)	55 (67)	56 (68)	57 (69)	58 (70)	59 (71)	60 (71.1)	61 (72)	62 (72.1)	63 (73)	64 (77)	65	66	67 (81)	68 (82)	69 (84)	70 (85)	71 (86)	72 (88)
									P. ct.	*P. ct.*	*P. ct.*	*P. ct.*			*Inches.*	*Min.*	*P. ct.*	*P. ct.*	*P ct.*	*P. ct.*
S-501	78.8	83	94.9	6.47	7.59	7.76	8.68	8.98	55.2	57.1	55.9	4.1	1.2	2.5	7.4	15	8.4	11.2	0.0	80.4
S-502	80.8	83	97.3	6.92	8.11	8.30	9.38	9.64	59.7	61.3	59.7	3.0	1.4	2.0	7.4	15	8.0	11.6	.0	80.4
S-503	81.2	83	97.8	6.57	7.69	7.90	8.80	9.05	56.0	57.5	56.0	4.0	1.0	2.0	7.2	15	8.2	11.4	.0	80.4
S-504	85.4	83	102.9	6.69	7.85	8.01	9.05	9.29	57.5	59.0	57.7	7.0	3.1	6.2	7.2	15	8.9	10.3	.0	80.8
S-505	83.2	83	100.2	6.99	8.20	8.37	9.42	9.68	60.0	61.6	60.4	11.0	6.2	7.5	7.3	15	10.0	9.5	.0	80.5
S-506	88.0	83	106.0	6.82	8.00	8.26	9.30	9.66	59.2	61.5	60.0	20.0	11.9	14.5	7.8	5	11.5	7.8	.0	80.7
S-507	83.8	83	101.0	7.24	8.47	8.72	9.86	10.07	62.7	64.1	62.6	15.8	9.2	13.5	7.8	5	11.5	7.7	.1	80.7
S-508	87.4	83	105.3	7.14	8.36	8.57	9.76	9.93	62.0	63.1	61.4	20.8	11.3	14.5	7.9	5	12.3	6.4	.1	81.2
S-509	87.9	83	105.9	6.81	7.97	8.18	9.38	9.40	59.9	60.0	58.4	33.6	20.2	30.0	6.8	5	12.3	6.4	.1	81.2
S-510	85.4	83	102.9	6.89	8.05	8.22	9.27	9.43	59.2	60.2	58.9	27.3	15.3	23.0	7.7	5	12.3	5.8	.1	81.8

SERIES 2.

S-511	82.6	83	99.5	6.63	7.72	7.97	8.90	9.18	56.6	58.4	57.1	10.4	5.5	10.0	7.2	15	9.2	9.9	0.0	80.9
S-512	83.7	83	100.8	7.07	8.25	8.45	9.40	9.57	59.7	60.8	59.6	11.1	6.0	8.5	7.3	15	9.6	9.8	.0	80.6
S-513	85.0	83	102.4	7.18	8.35	8.53	9.74	9.83	61.8	62.4	61.1	9.0	4.5	7.0	7.6	15	9.3	10.1	.0	80.6
S-514	86.0	83	103.6	6.68	7.79	8.00	8.97	9.17	57.0	58.3	57.0	14.3	8.0	10.5	7.4	15	8.5	11.0	.0	80.5
S-515	83.1	83	100.1	7.01	8.20	8.45	9.47	9.69	59.8	61.2	60.2	9.7	4.8	6.5	7.4	15	9.4	10.1	.0	80.5
S-516	83.5	83	100.6	6.90	8.06	8.29	9.26	9.60	58.8	60.9	59.7	25.4	14.9	18.5	7.1	5	10.7	8.3	.1	80.9
S-517	84.6	83	101.9	7.04	8.23	8.42	9.50	9.73	60.6	62.1	60.4	20.0	11.3	18.0	7.4	5	10.8	8.2	.1	80.9
S-520	83.7	83	100.8	7.20	8.43	8.66	9.76	9.93	62.3	63.4	61.8	16.1	9.4	14.0	7.6	5	11.4	7.5	.1	81.0
S-521	85.1	83	102.5	6.78	7.95	8.18	9.33	9.50	59.5	60.6	58.8	31.0	17.3	23.5	7.7	5	12.6	6.0	.2	81.2
S-522	83.9	83	101.1	6.96	8.17	8.42	9.43	9.82	60.2	62.6	60.8	21.2	12.7	16.5	7.6	5	11.6	7.3	.0	81.1

SERIES 3.

S-523	80.8	83	97.3	7.25	8.48	8.67	9.86	10.02	63.1	64.1	62.1	15.7	8.0	13.5	7.2	15	10.8	8.5	0.1	80.6
S-545	81.3	83	98.0	7.21	8.42	8.76	10.04	10.10	63.9	64.2	62.6	10.8	5.0	7.0	7.2	15	11.0	8.0	.0	81.0
S-525	80.8	83	97.3	7.35	8.55	8.75	9.66	9.95	61.8	63.6	62.3	7.8	2.1	4.5	7.5	15	9.8	9.6	.0	80.6
S-526	82.0	83	98.8	7.30	8.54	8.73	9.85	9.99	62.6	63.5	62.0	13.0	6.5	9.0	7.2	15	11.0	......	......	......
S-527	81.4	83	98.1	7.76	9.02	9.25	10.40	10.60	66.4	67.6	66.1	8.0	4.3	6.5	7.4	15	10.7	......	......	......
S-530	82.2	83	99.0	7.11	8.28	8.48	9.50	9.80	60.5	62.4	60.9	23.9	12.8	18.5	7.8	5	11.9	......	......	......
S-531	81.8	83	98.6	7.40	8.62	8.85	10.00	10.17	63.8	64.8	63.4	14.6	6.8	11.0	7.4	5	11.1	......	......	......
S-532	83.0	83	100.0	7.58	8.84	9.09	10.23	10.40	65.0	66.1	64.5	15.8	6.3	8.0	7.9	5	12.1	......	......	......
S-533	82.3	83	99.2	7.20	8.39	8.67	9.80	9.90	62.2	62.9	61.7	28.2	15.4	23.5	7.4	5	12.8	......	......	......
S-534	84.1	83	101.3	7.62	8.90	9.08	10.38	10.41	66.1	66.3	64.6	21.4	11.6	18.0	7.5	5	14.0	4.3	.6	81.1

SERIES 4.

S-585	78.4	83	94.5	6.53	7.65	7.86	9.38	9.42	61.4	61.6	57.9	4.9	0.1	6.0	7.2	15	8.9	11.1	0.1	79.9
S-586	73.9	83	89.0	6.50	7.59	7.79	9.38	9.74	61.4	63.8	58.6	3.0	.1	4.0	6.8	15	8.4	11.7	.1	79.8
S-587	85.4	83	102.9	6.93	8.14	8.37	9.73	9.75	63.4	63.6	61.6	14.0	4.0	17.5	6.6	5	10.4	9.2	.0	80.4
S-588	85.0	83	102.4	6.91	8.12	8.42	9.61	9.83	62.9	64.3	62.5	11.3	3.4	14.5	7.0	5	10.5	9.1	.0	80.4

SERIES 5.

S-603	80.3	83	96.7	7.39	8.56	8.81	10.48	10.51	68.6	68.8	65.7	9.8	4.0	6.0	7.1	15	10.6	8.7	0.1	80.6
S-604	81.9	83	98.7	7.60	8.81	9.07	10.89	10.98	71.4	71.9	68.0	4.8	1.5	3.0	7.0	15	11.4	7.8	.1	80.7
S-605	81.8	83	98.6	7.43	8.59	8.86	10.49	10.71	68.8	70.2	67.0	12.6	4.0	7.0	6.7	5	10.4	8.9	.0	80.7
S-606	81.2	83	97.8	7.39	8.57	8.83	10.41	10.41	68.3	68.3	65.5	16.5	8.4	11.0	6.8	5	11.1	8.0	.1	80.8

SERIES 6.

S-576	78.1	83	94.1	7.32	8.62	8.84	10.51	10.62	68.6	69.3	64.7	4.2	1.0	3.5	6.8	15	11.6	7.9	0.1	80.4
S-577	70.1	83	84.5	6.76	7.95	8.34	10.10	10.42	66.0	68.1	63.0	3.8	.8	3.0	7.2	15	10.3	9.6	.0	80.1
S-598	73.3	83	88.3	7.46	8.60	8.80	10.38	10.22	67.8	66.7	64.3	20.4	10.8	16.5	6.8	5	12.6	6.8	.1	80.5
S-600	78.4	83	94.5	7.31	8.46	8.70	10.01	10.00	65.2	65.1	63.4	13.7	7.7	15.0	6.6	5	11.6	7.6	.1	80.7

A summary of the principal results of each series of tests is presented in Table 3.

TABLE 3.—*Principal results of furnace tests.*

	Series No.	Auxiliaries used.									
		None.		Air over fire.		Air through bridge wall.		Steam jets over fire.		Steam jets and air over fire.	
		Coking method.	Alternate spreading method.	Coking method.	Alternate spreading method.	Coking method.	Alternate spreading method.	Coking method.	Alternate spreading method.	Coking method.	Alternate spreading method.
Efficiency of boiler and grate, per cent	1	55.9	60.0	59.7	62.6	56.0	61.4	57.7	58.4	60.4	58.9
Do	2	57.1	59.7	59.6	60.4	61.1	61.8	57.0	58.8	60.2	60.8
Do	3	62.1	60.9	62.6	63.4	62.3	64.5	62.0	61.7	66.1	64.6
Do	4	......	......	57.9	61.6	......	......	......	......	58.6	62.5
Do	5	......	......	65.7	67.0	......	......	......	......	68.0	65.5
Do	6	......	......	64.7	64.3	......	......	......	......	63.0	63.4
Average density of smoke (per cent of black)	1	4.1	20.0	3.0	15.8	4.0	20.8	7.0	33.6	11.0	27.3
Do	2	10.4	25.4	11.1	20.0	9.0	16.1	14.3	31.0	9.7	21.2
Do	3	15.7	23.9	10.8	14.6	7.8	15.8	13.0	28.2	8.0	21.4
Do	4	......	......	4.9	14.0	......	......	......	......	3.0	11.3
Do	5	......	......	9.8	12.6	......	......	......	......	4.8	16.5
Do	6	......	......	4.2	20.4	......	......	......	......	3.8	13.6
Maximum minutes of dense smoke per hour	1	2.5	14.5	2.0	13.5	2.0	14.5	6.2	30.0	7.5	23.0
Do	2	10.0	18.5	8.5	18.0	7.0	14.0	10.5	23.5	6.5	16.5
Do	3	13.5	18.5	7.0	11.0	4.5	8.0	9.0	23.5	6.5	18.0
Do	4	......	......	6.0	17.5	......	......	......	......	4.0	14.5
Do	5	......	......	6.0	7.0	......	......	......	......	3.0	11.0
Do	6	......	......	3.5	16.5	......	......	......	......	3.0	15.0
Temperature of flue gas, °F	1	601	554	575	536	576	541	581	545	549	556
Do	2	630	550	581	559	576	565	577	542	587	534
Do	3	568	561	526	537	549	529	542	526	534	500
Do	4	......	......	588	583	......	......	......	......	587	563
Do	5	......	......	574	559	......	......	......	......	526	547
Do	6	......	......	537	563	......	......	......	......	560	559
Carbon dioxide in flue gas	1	8.4	11.5	8.0	11.5	8.2	12.3	8.9	12.3	10.0	12.3
Do	2	9.2	10.7	9.6	10.8	9.3	11.4	8.5	12.6	9.4	11.6
Do	3	10.8	11.9	11.0	11.1	9.8	12.1	11.0	12.8	10.7	14.0
Do	4	......	......	8.9	10.4	......	......	......	......	8.4	10.5
Do	5	......	......	10.6	10.4	......	......	......	......	11.4	11.1
Do	6	......	......	11.6	12.6	......	......	......	......	10.3	11.6
Draft at breaching, inches of water	1	.33	.20	.33	.18	.30	.15	.27	.17	.20	.14
Do	2	.30	.17	.23	.18	.22	.15	.24	.12	.23	.13
Do	3	.19	.19	.18	.18	.25	.17	.21	.12	.17	.12
Do	4	......	......	.23	.18	......	......	......	......	.24	.18
Do	5	......	......	.15	.13	......	......	......	......	.13	.12
Do	6	......	......	.34	.30	......	......	......	......	.41	.34
Quality of refuse, per cent clinker	1	49	70	52	67	49	72	58	64	59	66
Do	2	52	58	53	66	55	62	62	70	63	69
Do	3	65	63	46	58	58	61	56	59	54	64
Do	4	......	......	41	43	......	......	......	......	32	39
Do	5	......	......	38	50	......	......	......	......	45	49
Do	6	......	......	35	52	......	......	......	......	27	55

DISCUSSION OF TEST RESULTS.

EFFECT OF CONSTRUCTION OF FURNACE.

It will be noticed that in the single-pass tests the significant results in Table 2 are much the same for series 1, 2, and 4, whereas, with a few exceptions, they are uniformly better for series 3 and 5. In general, the percentage of clinker in the refuse, the amount of smoke emitted, and the flue-gas temperature are less, and therefore more favorable, in the third and fifth series than in the other three; the water evaporated per pound of fuel, the efficiency of the boiler and grate, and the percentage of CO_2 in the uptake gases are greater and also more favorable.

In the third series the removal of that part of the combustion arch directly over the fuel bed exposed the comparatively cool boiler shell to the radiant heat from the incandescent coke, thus lowering the temperatures of the furnace, the fuel bed, and the gases entering the tubes, resulting in lower flue-gas temperatures and higher over-all efficiency. In explanation of this result it may be stated that so long as combustible gases are kept at a temperature sufficiently high to allow of their combination, the advantages to be gained by a further elevation of their temperature are partly if not entirely offset by the resulting disadvantages.

The lower temperature of the fuel bed resulted in the formation of less clinker, and although no measurements of furnace or fuel-bed temperatures were made, the difference was decidedly evident, especially to the fireman when stoking or cleaning fires.

In the fourth series the effect of the removal of the arch over the fire was apparent in the low percentage of clinker formed, but because of the screening of a part of the water-cooled surface in the combustion chamber from the direct radiation, the temperatures of the gases entering the tubes were greater, so that flue-gas temperatures were higher and the over-all efficiency was lower.

In the fifth series, the removal of the horizontal tile in the combustion chamber exposed the shell to considerable radiation from the hot brickwork and resulted in higher efficiencies than were attained with any of the previous settings, and without the emission of any objectionable amount of smoke. It is believed that this freedom from objectionable smoke results from the adequacy of the mixing devices and the sustaining of the temperature of the gases above the ignition point by the action of the brickwork remaining in the combustion chamber.

The results of the sixth series with the double pass showed a substantial gain in efficiency over those of the fourth, owing to the extra length of gas travel, the furnace construction being the same, but because of the increased resistance of the gas passages, the maximum capacity that could be developed with a given available draft was less than with a single pass.

The decreased smoke emission during the tests of the last three series is to be explained largely by the fact that the lower furnace temperatures, owing to the removal of part of the arch, produced a more gradual distillation of the volatile or gaseous part of the coal, but without cooling to such a degree as to prevent proper combustion.

As the combustible gases were more slowly and gradually driven off, it was possible to obtain a better mixture of the air with them, which in turn resulted in less smoke being produced. The observations showed the duration of the smoke emission to be about the same for the tests of all six series, but in the last three series dense smoke was emitted immediately after firing for much shorter periods than in the earlier tests.

The higher average carbon dioxide content of the gases in the tests of the last three series is due largely to the freedom from clinker troubles, which has already been mentioned. The deflection arch, which was added for series 2, can probably be credited with a general, though not marked, reduction of smoke in the tests of that series as compared with those of the first. This is not a true indication, however, of the effect of the addition of the deflection arch, because the baffle or curtain wall which was in the combustion chamber throughout both series of tests produced somewhat the same effect—a mixing of the gases—that the deflection arch was designed to accomplish.

Attention is also called to the smoke observations for the first four tests of series 1. These tests do not support the conclusions drawn relative to the effect of various changes, in so far as smoke is concerned. The lesser amounts of smoke produced in these tests as compared to that produced in the rest of the tests are doubtless due in part to the greater amount of air supplied for combustion, as indicated by the gas analyses, and possibly also to a slight difference in the coal used.

EFFECT OF METHOD OF FIRING.

A comparative study of the two groups of tests in each series shows that less clinker was formed and less smoke emitted when the coking method of firing was employed. On the other hand, the results of tests conducted with the alternate-spreading method of firing generally show greater evaporation per pound of fuel (higher efficiency), higher percentages of carbon dioxide in the uptake gases, and lower exit temperatures of these gases. With a given draft, higher rates of combustion and higher capacities can be obtained with the alternate-spreading method, because the resistance of the fuel bed to the passage of air is lower and the drop in draft through the boiler is less with the smaller quantity of gases handled when the higher percentages of carbon dioxide are obtainable.

These relations of higher carbon dioxide content and lower uptake temperatures are the reverse of those which are usually believed to obtain in boiler practice. The rates of combustion for the tests of any one series are so nearly constant that they may be so considered, and there is nothing to indicate serious error in either the gas analyses or the temperature measurements. The authors offer the following explanation for the seeming incongruity in the results of the two groups. With the spreading method of firing the carbon dioxide content is higher, indicating that a smaller quantity of hot gases is being formed. The gases, although at a higher temperature over the fire, are reduced in temperature more rapidly both before and after entering the boiler tubes than the larger quantities formed by the coking method are. The result is that the temperature of the gases entering the tubes is only slightly higher in the tests wherein the spreading method of firing was used, and as the quantity of gas is less the fall of temperature through the tubes is more rapid and the gases therefore emerge with a lower final temperature. If the curves for the two series of average temperature drop along the tubes were plotted, they would cross each other possibly somewhere near the middle. The difference in uptake temperatures would grow less with increased rates of combustion or increased length of tubes, and might even be the other way with sufficiently high rates of combustion.[a]

The continual raking and stirring of the fire incident to the coking method of firing shook more of the ash through the grates and left less of it on them to fuse into clinker than the procedure in the other method of firing did. The tabulated results of the tests show a marked difference in the amount of clinker formed under the two methods of handling, and the analyses of the samples of refuse also show that the loss of combustible matter in the refuse was no greater from a fire so raked and stirred than from one fed by the spreading method.

The smaller percentages of carbon dioxide in the flue gases when the firing was done by the coking method may be explained in part by the fact that the interval between firings was longer in such tests than when the other method of firing was employed, and consequently the tendency for the fuel bed to burn through in spots and let more air pass was also greater. Another possible explanation for the greater excess of air admitted in firing by the coking method is that there is evidently more of a tendency for the fuel bed to burn through at the back.

With the particular furnace arrangements and the other conditions under which these tests were conducted a comparison of the two methods of firing as regards smoke prevention shows decidedly in favor of the coking method. The greater amount of smoke emitted when the alternate spreading method of firing was used is probably due to two causes, namely, inadequacy of the supplementary air openings to admit the required air immediately after firing and insufficient facilities for mixing the air and combustible gases before they reached the tubes. Had the supplementary air openings been of greater capacity the amount of smoke produced by the spreading method would doubtless have been lessened. A further disadvantage of the spreading method of firing is the more frequent attention required by the firemen to attain the same degree of smokelessness, which, in case one fireman had to tend more than one boiler, would introduce operating difficulties.

---

[a] For further discussion of these relations see Ray, W. T., and Kreisinger, Henry: The transmission of heat into steam boilers, Bull. 18, Bureau of Mines, 1912, pp. 144-165.

EFFECT OF AUXILIARY DEVICES.

The results of the tests show that an increase in efficiency and a decrease in the time of emission of dense smoke resulted from the admission of the supplementary air. With the furnace and combustion chamber arranged as shown in figures 1, 2, or 3, it seemingly made little difference whether the extra air was admitted through the openings at the front of the furnace or through those in the bridge wall. The effectiveness of admitting air through the bridge wall is, however, more largely dependent on the facilities for mixing the gases in the combustion chamber than that of admitting air over the firing doors, and this point should be kept in view when the relative value of the two methods is considered in the design of boiler furnaces. This conclusion is substantiated by the results obtained in several trials of bridge-wall air admission with the setting shown in Plate I. The supplementary air is admitted below the gases coming over the bridge wall, and the mixing devices do not intimately mix the air and gases in a vertical plane, resulting in stratification and the failure of this method of reducing smoke.

As already stated, only one position and one design of steam jet was tried, but under the conditions of these tests the results seem to discourage rather than to encourage the use of the steam jet as an auxiliary mixer of gases. It is quite possible, however, that better results might have followed the use of steam jets differently arranged. The authors believe that further experiments with hand-fired furnaces for this type of boiler will show the possibility of constructing a furnace that will produce practically the same results with supplementary air alone as with air and any arrangement of steam jets. In view of the prejudice of many engineers against the use of steam jets, the development of a furnace that, without excessive initial or maintenance costs, will give as good results without jets is greatly to be desired.

SUMMARY AND CONCLUSIONS.

Certain conclusions have been drawn from the results of the tests described in this paper. As previously stated, some of these deductions are general and are believed to apply to the settings of practically all hand-fired boilers of the return-tubular type when fired as described in this paper. Other conclusions are more restricted in application, and may not be true under conditions other than those described herein. A summary of the general deductions has been given, but is repeated here.

The operation at rating of hand-fired boilers of this type in most American cities without violation of their smoke ordinances is physically possible and with proper boiler-room supervision can be accomplished, although it requires an attention to firing methods not given by the average fireman.

The prevention of smoke may be more easily accomplished when the coking method of firing is employed than when the alternate-spreading method is used.

The use of supplementary air immediately after firing tends to increase the over-all efficiency and to prevent smoke.

A brick arch placed directly over the fire and underneath the boiler shell results in lower over-all efficiency and in the production of more smoke.

The screening of heating surface in the combustion chamber from direct radiation from the brickwork tends to lower the combined efficiency.

A deflection arch of the form shown in figures 2 and 3 produces a better mixture of the furnace gases and thereby aids in obtaining proper combustion conditions; the same effect is produced by the wings and piers illustrated in Plate I.

The following statements are based upon the tests described in this paper, but may not be true under different conditions:

The devices for admitting air at the bridge wall and at the front of the furnace, shown in figures 1, 2, and 3, appear to be equally effective in reducing the amount of smoke and to result in approximately the same over-all efficiency.

Although no complete tests were made on the furnace arrangement shown in figure 4, using air admission at the bridge wall, enough trials were made to prove that with this furnace such a method of admitting supplementary air was not effective in reducing the amount of smoke.

Steam jets, as arranged in this furnace, fail to show a sufficient gain in efficiency or smoke reduction to justify their use.

PUBLICATIONS ON FUEL TECHNOLOGY.

A limited supply of the following publications of the Bureau of Mines is available for free distribution. Requests for all publications can not be granted and applicants should limit their selection to publications that may be of especial interest to them. Requests for publications should be addressed to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 1. The volatile matter of coal, by H. C. Porter and F. K. Ovitz. 1910. 56 pp., 1 pl., 9 figs.

BULLETIN 2. North Dakota lignite as a fuel for power-plant boilers, by D. T. Randall and Henry Kreisinger. 1910. 42 pp., 1 pl., 7 figs.

BULLETIN 3. The coke industry of the United States as related to the foundry, by Richard Moldenke. 1910. 32 pp.

BULLETIN 4. Features of producer-gas power-plant development in Europe, by R. H. Fernald. 1910. 27 pp., 4 pls., 7 figs.

BULLETIN 5. Washing and coking tests of coal at Denver, Colo., July 1, 1908, to June 30, 1909, by A. W. Belden, G. R. Delamater, J. W. Groves, and K. M. Way. 1910. 62 pp., 1 fig.

BULLETIN 6. Coals available for the manufacture of illuminating gas, by A. H. White and Perry Barker, compiled and revised by H. M. Wilson. 1911. 77 pp., 4 pls., 12 figs.

BULLETIN 7. Essential factors in the formation of producer gas, by J. K. Clement, L. H. Adams, and C. N. Haskins. 1911. 58 pp., 1 pl., 16 figs.

BULLETIN 8. The flow of heat through furnace walls, by W. T. Ray and Henry Kreisinger. 1911. 32 pp., 19 figs.

BULLETIN 12. Apparatus and methods for the sampling and analysis of furnace gases, by J. C. W. Frazer and E. J. Hoffman. 1911. 22 pp., 6 figs.

BULLETIN 13. Résumé of producer-gas investigations, October 1, 1904, to June 30, 1910, by R. H. Fernald and C. D. Smith. 1911. 393 pp., 12 pls., 250 figs.

BULLETIN 14. Briquetting tests of lignite at Pittsburgh, Pa., 1908–9; with a chapter on sulphite-pitch binder, by C. L. Wright. 1911. 64 pp., 11 pls., 4 figs.

BULLETIN 16. The uses of peat for fuel and other purposes, by C. A. Davis. 1911. 214 pp., 1 pl., 1 fig.

BULLETIN 18. The transmission of heat into steam boilers, by Henry Kreisinger and W. T. Ray. 1912. 180 pp., 78 figs.

BULLETIN 23. Steaming tests of coals and related investigations, September 1, 1904, to December 31, 1908, by L. P. Breckenridge, Henry Kreisinger, and W. T. Ray. 1912. 380 pp., 2 pls., 94 figs.

BULLETIN 24. Binders for coal briquets, by J. E. Mills. 56 pp., 1 fig. Reprint of United States Geological Survey Bulletin 343.

BULLETIN 27. Tests of coal and briquets as fuel for house-heating boilers, by D. T. Randall. 44 pp., 3 pls., 2 figs. Reprint of United States Geological Survey Bulletin 366.

BULLETIN 28. Experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 51 pp. Reprint of United States Geological Survey Bulletin 323.

Bulletin 29. The effect of oxygen in coal, by David White. 80 pp., 3 pls. Reprint of United States Geological Survey Bulletin 382.

Bulletin 30. Briquetting tests at the United States fuel-testing plant at Norfolk, Va., 1907–8, by C. L. Wright. 41 pp., 9 pls. Reprint of United States Geological Survey Bulletin 385.

Bulletin 31. Incidental problems in gas-producer tests, by R. H. Fernald, C. D. Smith, J. K. Clement, and H. A. Grine. 29 pp., 8 figs. Reprint of United States Geological Survey Bulletin 393.

Bulletin 32. Commercial deductions from comparisons of gasoline and alcohol tests of internal-combustion engines, by R. M. Strong. 38 pp. Reprint of United States Geological Survey Bulletin 392.

Bulletin 33. Comparative tests of run-of-mine and briquetted coal on the torpedo boat *Biddle*, by W. T. Ray and Henry Kreisinger. 50 pp., 10 figs. Reprint of United States Geological Survey Bulletin 403.

Bulletin 34. Tests of run-of-mine and briquetted coal in a locomotive boiler, by W. T. Ray and Henry Kreisinger. 33 pp., 9 figs. Reprint of United States Geological Survey Bulletin 412.

Bulletin 35. The utilization of fuel in locomotive practice, by W. F. M. Goss. 29 pp., 8 figs. Reprint of United States Geological Survey Bulletin 402.

Bulletin 36. Alaskan coal problems, by W. L. Fisher. 1911. 32 pp., 1 pl.

Bulletin 37. Comparative tests of run-of-mine and briquetted coal on locomotives, including torpedo-boat tests, and some foreign specifications for briquetted fuel, by W. F. M. Goss. 58 pp., 4 pls., 35 figs. Reprint of United States Geological Survey Bulletin 363.

Bulletin 39. The smoke problem at boiler plants, a preliminary report, by D. T. Randall. 31 pp. Reprint of United States Geological Survey Bulletin 334, revised by S. B. Flagg.

Bulletin 40. The smokeless combustion of coal in boiler furnaces, with a chapter on central heating plants, by D. T. Randall and H. W. Weeks. 188 pp., 40 figs. Reprint of United States Geological Survey Bulletin 373, revised by Henry Kreisinger.

Bulletin 41. Government coal purchases under specifications, with analyses for the fiscal year 1909–10, by G. S. Pope; with a chapter on the fuel-inspection laboratory of the Bureau of Mines, by J. D. Davis. 1912. 97 pp., 3 pls.

Bulletin 43. Comparative fuel values of gasoline and denatured alcohol in internal-combustion engines, by R. M. Strong and Lauson Stone. 1912. 243 pp., 3 pls., 32 figs.

Bulletin 49. City smoke ordinances and smoke abatement, by S. B. Flagg. 1912. 55 pp.

Bulletin 54. Foundry-cupola gases and temperatures, by A. W. Belden. 1913. 29 pp., 3 pls., 16 figs.

Bulletin 55. The commercial trend of the producer-gas power plant in the United States, by R. H. Fernald. 1913. 93 pp., 1 pl., 4 figs.

Bulletin 58. Fuel-briquetting investigations, July, 1904, to July, 1912, by C. L. Wright. 1913. 277 pp., 21 pls., 3 figs.

Bulletin 63. Sampling coal deliveries, and types of Government specifications for the purchase of coal, by G. S. Pope. 1913. 68 pp., 4 pls., 3 figs.

Technical Paper 2. The escape of gas from coal, by H. C. Porter and F. K. Ovitz. 1911. 14 pp., 1 fig.

Technical Paper 5. The constituents of coal soluble in phenol, by J. C. W. Frazer and E. J. Hoffman. 1912. 20 pp., 1 pl.

Technical Paper 8. Methods of analyzing coal and coke, by F. M. Stanton and A. C. Fieldner. 1913. 42 pp., 12 figs.

Technical Paper 16. Deterioration and spontaneous combustion of coal in storage, a preliminary report, by H. C. Porter and F. K. Ovitz. 1912. 14 pp.

Technical Paper 20. The slagging type of gas producer, with a brief report of preliminary tests, by C. D. Smith. 1912. 14 pp., 1 pl.

Technical Paper 31. Apparatus for the exact analysis of flue gas, by G. A. Burrell and F. M. Seibert. 1913. 12 pp., 1 fig.

Technical Paper 37. Heavy oil as fuel for internal-combustion engines, by I. C. Allen. 1913. 36 pp.

Technical Paper 55. The production and use of brown coal in the vicinity of Cologne, Germany, by C. A. Davis. 1913. 15 pp.

○